

# Review and Analysis of Hydraulic Excavator

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**Abstract** – Valve-controlled hydraulic actuation systems are favoured in many applications due to their fast response, high power-to-weight ratio, and stability under variable working conditions. Efficiency, however, is the main disadvantage of these systems. Pump-controlled hydraulic actuators, on the other hand, eliminate energy losses in throttling valves and require less cooling. Furthermore, they inherently hold the ability to recover energy from assistive loads. Pump-controlled circuits for double-rod cylinders are well developed and are implemented in many industrial applications, including aviation. However, pump-controlled circuits for single-rod cylinders usually experience performance issues during specific modes of operation. In this paper, a new circuit using two valves to compensate for the differential flow of single-rod actuators is proposed. They have a minimum throttling effect in all other operating regions to preserve the efficiency. The new circuit has been experimentally evaluated. Its performance has also been compared with three other previously proposed circuits. The proposed circuit displays an improved performance, besides being capable of energy regeneration.

**Keywords** – Hydraulic Excavator, Excavator Boom.

## I. INTRODUCTION

As automation technology continues to be integrated into industrial and mobile machinery, more precise control of hydraulic cylinders will assist in the achievement of desired response characteristics. Hydraulic circuits with fast dynamic response are often characterized by low power efficiency; on the other hand, energy-efficient circuits under certain circumstances, can demonstrate slow transient responses. Continuously rising energy costs combined with the demand on high performance has necessitated that hydraulic circuits become more efficient yet still demonstrate superior dynamic response. This thesis introduces a new hydraulic circuit configuration which demonstrates high dynamic performance and high efficiency. Hydraulic systems are used to transfer energy by converting mechanical energy to fluid energy, and then back to mechanical energy. The principle reason for converting to fluid energy is the convenience of transferring energy to a new location. Hydraulic drives have many advantages over other technologies. The ratio of weight, volume and inertia to available power is significantly lower than in electromechanical drives, especially for linear motion. The dynamic performance is superior when compared to electrical or electrical-mechanical drive systems in large power drive systems [Li et al., 1998]. For those systems that require an output power larger than 10 kW and a fast response speed, hydraulic drive systems are often the appropriate choice. Hydraulic systems are especially suitable for those operations characterized by abrupt loading, frequent stops and starts, reversing and speed variations that cause sharp

peak, cyclic and fluctuating power demands. These advantages make them very popular in applications such as aircraft, mobile equipment, lifting machines and forest machines.

Excavator is one of the most important machinery in engineering machinery. Excavators are widely used in construction, railway, water conservancy, mining and other industries [1], [2]. There are many variations in hydraulic excavators. They may be either crawler or rubber-tire-carrier-mounted, and there are many different operating attachments. Hydraulic excavator consists of three main parts: undercarriage, upper structure and the working device, the upper structure rotates on the undercarriage [3].

The working device of a hydraulic excavator mainly consists of boom, arm, bucket, boom cylinder, arm cylinder, and bucket cylinder [4]. The boom and boom cylinder composed the boom linkage mechanism, the arm and arm cylinder composed the arm linkage mechanism, and the bucket and bucket's cylinder and linkage mechanism composed bucket mechanism, all of above linkage mechanism connected with each other by means of pin-hinged [6]. Excavator digs, elevates, swings and dumps material by the action of its mechanism of working devices [5]. The working devices of excavator works under complex load in serve working conditions [3]. So the strength, reliability and durability of excavator working device are directly related to the excavator's working performance and efficiency, therefore the strength and reliability research of the working device has a very important significance [7].

This paper reviewed the experimental analysis of performance of a simple single acting hydraulic cylinder with different valve and sensor of hydraulic excavator

including all other parameter (e.g, hydraulic fluid, lubricants between cylinder and piston etc.). Furthermore, the developed model has to be consolidated afterwards allowing the performance of the hydraulic control system simulations in MATLAB/Simscape/Simhydraulics.

## II. LITERATURE REVIEW

Per-Willy Lazuli and Bjorn Victor Lund [8] presented in a study the results of modelling and simulation of a physical hydrostatic transmission with three different modelling tools; Simulink, SimHydraulics and Simulation X. The aim has been to get the simulations from the different models to be as similar as possible to the two measured pressures and the rotational speed of the load. The Simulation X model gave the best results compared with the measurements. The largest challenge has been to simulate the model in Simulink and to find the frictional losses in the hydraulic motor by performing different tests. The solver in Simulink could not solve the equations and it was difficult to find the tests for finding two of the friction parameters.

Boran Kilic [9] developed a dynamic model of the loader system of a backhoe-loader. Rigid bodies and joints in the loader mechanism and loader hydraulic system components are modelled and analysed in the same environment using the physical modelling toolboxes, Simhydraulics and Simmechanics, available inside the commercially available simulation software, MATLAB/Simulink. Interaction between the bodies and response of the hydraulic system are obtained by co-operating the mechanical and hydraulic analyses. System variables such as pressure, flow and displacement are measured on a physical machine and then compared with the simulation results. Simulation results are consistent with the measurement results. The main result of this work is the ability to determine the dynamic loads on the joints and attachments of the backhoe loader. In addition to that, prototyping time and costs can be highly reduced by implementing this model in the design process.

Weinan Cao, etc [10] analysed the necessity of research on Model and Simulation of ocean wave power generation platform of hydraulic lifting system. Aiming to the working condition and mechanism of self-elevating power-generating platform, the paper provided overall designing scheme and analysed the working principle of the system. By modelling and simulation of hydraulic system based on AME Sim software to set different parameter values for analysis of dynamic characteristics and stability of the system, which can help to find out the factors that influence the dynamic characteristics. This founding has a certain significant guiding meaning for the parameter optimization design of the jack up platform of hydraulic lifting system.

## III. SINGLE CYLINDER HYDRAULIC CIRCUIT ELEMENTS

Power supply section- pump, Elec- motor, engine  
Power control section- 3-way controller valve (or magnetic valve), controller  
Drive section- actuator, cylinder motor.

### 1. Specifications of the Circuit elements

Specification of Cylinder-  
Length of the stroke – 0.25 m

Bore size (area) – 0.002 m<sup>2</sup>  
Dead volume – 1 e-06  
Contact Stiffness – 1 e+07 N/m  
Contact Damping – 250Ns/m

Specification of Three Way Valve-  
Flow discharge coefficient – 0.7  
Leakage area – 1 e-06  
Laminar flow pressure ratio – 0.99  
Maximum opening – 0.01 m<sup>2</sup>  
Maximum opening area – 1 e-04 m<sup>2</sup>

Specification of Valve Actuator-  
Push-pin stroke – 0.01m  
Switching-on time – 0.1s  
Switching-off time – 0.1s  
Nominal signal value – 24

### 2. Related formula

i.3-way valve:

$$q = c d A (p)^{\frac{2}{3}} \cdot \frac{\square}{\square(\square + \square)}$$

$$\square = \square + \square$$

$$= \frac{\square}{\frac{Re \sigma * v}{2 (Cd * DH)^2}}$$

$$\square$$

$$\square(\square)$$

The flow rate is determined according to the following equations:

#### IV. DESCRIPTION

##### 1. Single acting hydraulic cylinder:

A single acting hydraulic cylinder is based on the concepts of pressure and piston effective area. With only one inlet through which an incompressible fluid, such as hydraulic oil, can be applied, a single acting hydraulic cylinder depends on the load or springs to retract the piston.

The Single-Acting Hydraulic Cylinder (Simple) block represents a simplified version of a hydraulic cylinder, developed for applications where only the basic cylinder functionality must be reproduced, in exchange for better numerical efficiency. For these reasons, such factors as fluid compressibility, friction, and leakages are assumed to be negligible. The hard stops are assumed to be fully inelastic, to eliminate any possible oscillations at the end of the stroke. The model is especially suitable for real-time and HIL (hardware-in-the-loop) simulation, if such simplifications are acceptable.



Fig-1.1. Block Diagram Basic Assumption  
Friction between moving parts is not.

taken into account.

Inertia effects are not taken into

Hydraulic Pump or Cylinder  
account.

Fluid compressibility is not taken into account.

Leakage flows are assumed to be negligible.

The hard stops are assumed to be fully inelastic, as explained above.

$$\frac{Q}{v * \rho} kHP = \frac{Dmax * \omega nom (1 - \eta_v * v nom * p nom)}{Q}$$

$$P = P_p - P_r$$

$$Q = \frac{128 Q}{Q} \quad Q$$

hp

##### 2. 3 Way Valve:

$$A_{leak} \text{ for } p \leq p_{set}$$

$$= \{A_{leak} + k(p - p_{set}) \text{ for } p_{set} < p < p_{max}$$

$$A_{max} \text{ for } p \geq p_{max}$$

A valve is a device that regulates, gives direction or controls the flow of a gases, liquids, fluidized solids, or slurries by opening, closing,

or partially giving obstacles to various passageways that's why valves with three ports are termed as 3 way valve.

$$\eta_{mec} =$$



Three-way valves are generally T- or L- shaped having fluid passageways inside the corresponding rotor.

The T valve might be used to permit connection of one inlet to either or both outlets or connection of the two outlets.

The L valve could be used to permit disconnection of both or connection of either but not both of two inlets to one outlet.

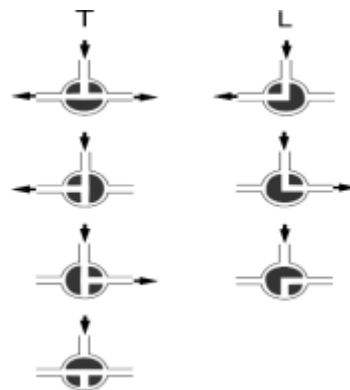


Fig-1.2. Three-way valve (T & L shape).

Working principle - The principle of a 3-way control valve is to close fluid flow in one pipe while opening fluid flow in another pipe, to mix fluid from two different pipes into one pipe, or to separate it from one pipe into two different pipes. The 3-way valve is categorized by its three ports. The valve is defined by its [m<sup>3</sup>/h] value. It expresses the volume of water that passes through the fully open valve in 1 hour with a pressure differential of 1 bar. In a mixing loop, a 3-way control valve can be used to control and regulate heating or cooling surfaces, radiator systems, floor heating/cooling, etc.

### 3. (2-position) Hydraulic valve actuator:

A valve actuator is the mechanism for opening and closing a valve. Hydraulic actuators convert pressure of fluid into motion. They are used on linear or quarter-turn valves. Most types of hydraulic actuators can be supplied with fail-safe features to close or open a valve under emergency circumstances.

2-position valve actuator is an actuator that drives 2-position directional discrete valves and assumes 2 positions: extended and retracted. The actuator is activated if the input signal crosses 50% of its nominal value. The actuator can be actuated only by positive signal, similar to the case of AC or DC electromagnets.

The push-pin reaches a hard stop after "switching-on" time, and retracts in "switching-off" time after the control signal is removed. The motion can be interrupted. The motion profile does not depend on load. The component has one physical signal input port and one physical signal output port.

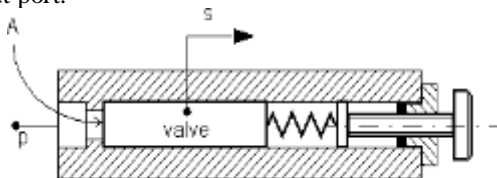


Fig-1.2 Valve Actuator Working principle-

Hydraulic valve actuator uses fluid pressure rather than instrumental air pressure for applying the force on the diaphragm and then to position valve stem. Most of the cases diaphragm is not used, instead piston is used to convert the hydraulic pressure into mechanical force.

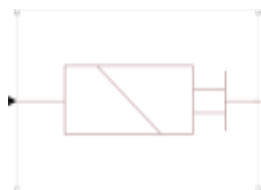


Fig-1.3 Block Diagram.

## V. PARAMETERS OF THE HYDRAULIC CIRCUIT.

The circuit under analysis is a single cylinder hydraulic circuit and its examination by the changes imparted by the variation of various parameters on which the working of the circuit depends.

This circuit shows a single-cylinder hydraulic cylinder controlled by an 3-way directional valve. It drives a load consisting of a mass, viscous friction, and preloaded spring. The pump unit is assumed to be powerful enough to maintain constant pressure at the valve inlet.

### A. Major parameters of the circuit components.

The valve is modelled by a 2-position Valve Actuator block (Valve Actuator) and a 3-way Directional Valve Block (3-way Valve). At the start of simulation, valve

orifices A and T are connected and the cylinder chamber is connected to the tank. When the control signal for the valve exceeds 12, the valve spool moves, connecting ports P and A and closing the path between valve ports A and T. As a result, the cylinder chamber is connected to the pressure source and moves the load.

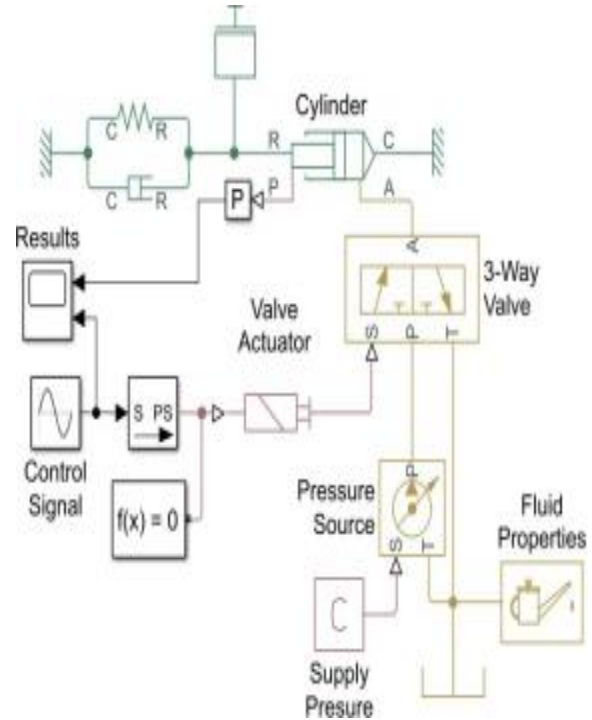


Fig-2.1 Electrical Circuit of Hydraulic Excavator

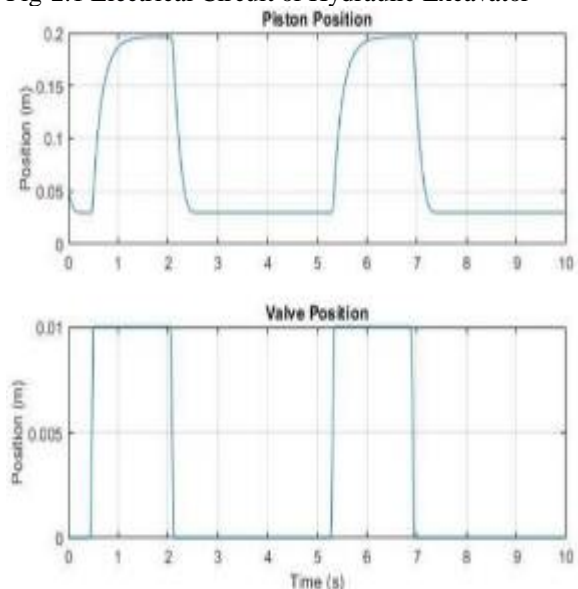


Fig-2.2 Simulation results from Simscape logging

The simulation result from the MATLAB Simulink model consists of a piston displacement vs valve control resultant graph which depends on various factors of the hydraulic circuit whose specification is mentioned above. Change in any given parameter bring a change in the output graph.

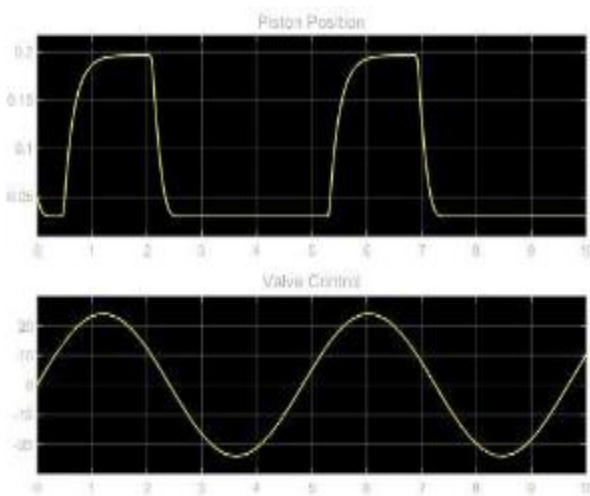


Fig-2.3 Valve control vs Piston Displacement.

## VI. RESULT

In hydraulic excavator, to improve life of pins and bushing, we suggest to use frequent lubrication to maintain the proper lubricant film to reduce wear and also to prevent rock dust, dirt, sand and water entering inside. These contaminants reduce pins and bushings life drastically and cause downtime and higher maintenance cost.

### The Cost of Improper Manual Lubrication

- Increased costs to repair and substitute parts.
- Machinery downtime due to unexpected repairs.
- Wearing down the pins, bushings and other components.
- Lower resale value for used equipment.
- Risk of excess lubrication and high consumption of lubricant.

That's why for hydraulic circuits in hydraulic excavators like DIESEL, ISO-32, and ISO-46 are used. So our objective was to check and analysis of the change of piston position during the change of lubricants.

1. When lubricant is changed to ISO-32: -

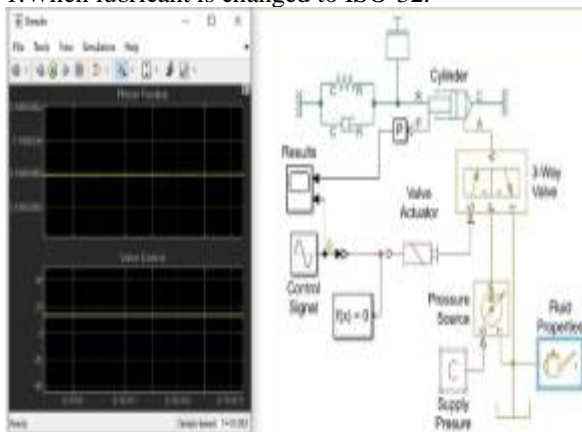


Fig-3.1 Piston position will be at 0.1966358

2. When it is changed to ISO-46: -

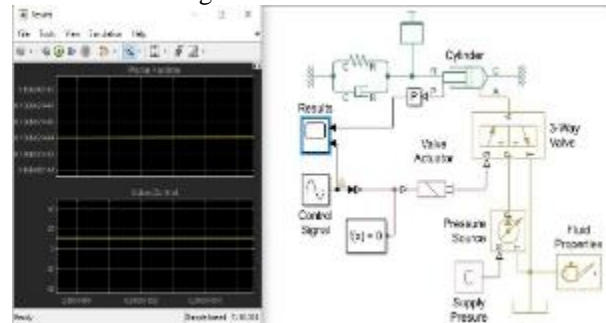


Fig- 3.2 Piston position will be 0.1966421

3. When it is changed to diesel: -

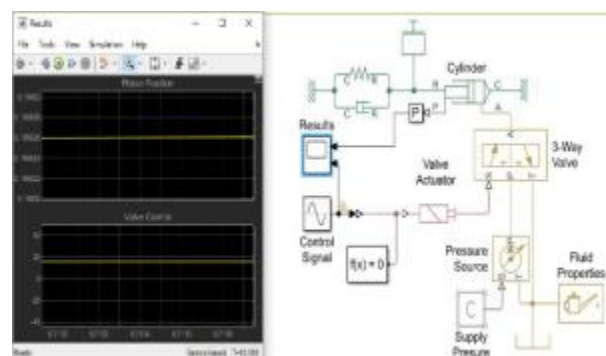


Fig-3.3 Piston position will be 0.196626

## VII. CONCLUSION

If value of any specification of the component is changed then the values of piston displacement and valve control will have a drastic change simultaneously. The change due to lubrication is not taken into consideration in the wholesome circuit but have a significant effect on the output signal if changed its type.

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